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USE OF A FOAM HEST TO SIMULATE LOW-YIELD NUCLEAR OVERPRESSURES.(U)
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USE OF A FOAM HEST TO SIMULATE LOW-YIELD NUCLEAR OVERPRESSURES

by

S. A. Kiger

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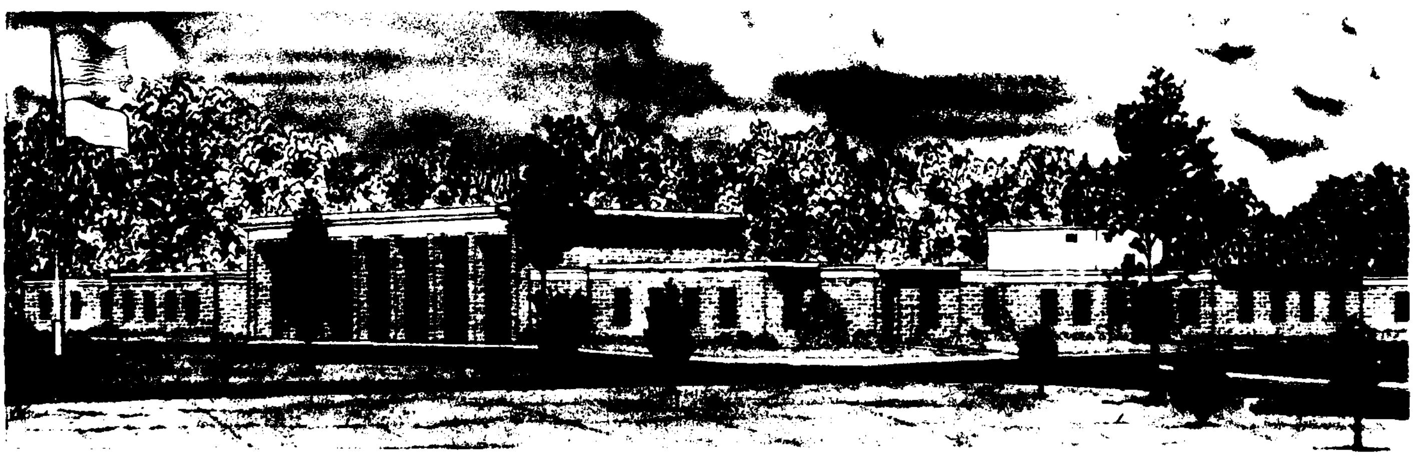
July 1981
Final Report



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A series of nine Foam HEST experiments was conducted. These tests were used to produce simulated nuclear overpressure environments in a research program to investigate the vulnerability of shallow-buried structures (SBS). The tests utilized charge densities varying from 6.9 kg/m^3 (0.43 lb/ft^3) to 58.6 kg/m^3 (3.6 lb/ft^3), producing overpressures from a low of approximately 5.5 MPa (800 psi) to a maximum of approximately 117 MPa (17,000 psi). Weapon

(Continued)

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20. ABSTRACT (Continued).

simulation was determined by comparing the measured airblast data records with theoretical airblast records and choosing the best fit in a least square sense. Weapons simulated varied from 0.04 TJ (0.01 kt) to approximately 33 TJ (8 kt). These tests were conducted on structural elements with 0.61-m (2-ft) and 1.2-m (4-ft) clear spans. Assuming a 4.9-m (16-ft) clear span in the prototype structure, the simulated weapons varied from 21.5 TJ (5.1 kt) to approximately 966 TJ (230 kt) on a prototype structure.

PREFACE

This paper was prepared for presentation at the Seventh International Symposium on Military Applications of Blast Simulation held at Medicine Hat, Alberta, Canada, 13-17 July 1981.

The research that yielded the results covered by this paper was sponsored by the Defense Nuclear Agency (DNA) under Subtask Y99QAXSC062, Work Unit 42, "Shallow-Buried Structures," and by the Office, Chief of Engineers, U. S. Army, under R&D Project 4A762719AT40, Task AO, Work Unit 008, "Target Response from Low-Yield Nuclear Surface and Subsurface Bursts." Dr. K. L. Goering, DNA, was Technical Monitor.

The research was conducted by personnel of the Structures Laboratory (SL), U. S. Army Engineer Waterways Experiment Station (WES), under the general supervision of Mr. Bryant Mather, Chief, SL, and Mr. W. J. Flathau, Assistant Chief, SL, and under the direct supervision of Mr. J. T. Ballard, Chief, Structural Mechanics Division (SMD), SL. This paper was prepared by Dr. S. A. Kiger of the Research Group, SMD.

COL Nelson P. Conover, CE, was Commander and Director of the WES during this study and the preparation and publication of this report. Mr. Fred R. Brown was Technical Director.

INTRODUCTION

The U. S. Army Engineer Waterways Experiment Station (WES) has recently completed a series of simulated nuclear overpressure tests on generic shallow-buried structural (SBS) models (References 1-5 and 7). The SBS research program is jointly sponsored by the Defense Nuclear Agency and by the Office, Chief of Engineers, U. S. Army. Seven 1/4-scale tests and two 1/8-scale tests were conducted in the SBS program. In every test, the airblast simulator was a High Explosive Simulation Technique (HEST) originally developed by the Air Force Weapons Laboratory (AFWL) (Reference 6). The HEST discussed in this paper is more specifically described as a Foam HEST because a low density plastic foam is used in constructing the charge cavity. This Foam HEST is used for the simulation of direct airblast loading on the ground surface to produce airblast-induced ground shock to load the buried structures. Airblast data collected in the nine SBS Foam HEST tests and the interpretation of these data in terms of weapon simulation will be discussed in this paper.

TEST DESCRIPTION

The objective of a HEST is to accurately reproduce over a large area the peak overpressure, rate of pressure decay, overpressure duration, and shock front velocity for a given nuclear yield and range or ranges. Figure 1 depicts a Foam HEST configuration typical of the tests discussed in this paper. In these tests, no attempt was made to reproduce an accurate shock front velocity because this was not an important parameter in this particular application. However, as discussed in Reference 6, accurate shock front velocities can be attained by an appropriate design of the weave of the explosive cord in the charge cavity.

Charge cavity depth, 11.4 cm (4.5 inches), and depth of the soil overburden, 0.8 m (32 inches), were the same for all the tests discussed here. Only the charge density was varied. An expanded view of a typical charge cavity is shown in Figure 2. The charge cavity consisted of plastic foam (Styrofoam) arranged in a configuration with sufficient gaps to distribute the explosives uniformly and also support the overburden without crushing. The cavity covered the entire test bed over an area 9.8 metres by 5.8 metres (32 feet by 19 feet) and was 11.4 cm (4.5 inches) deep, consisting of three layers of 3.8-cm- (1.5-inch-) thick foam. The first layer of foam was 3.8-cm- (1.5-inch-) wide strips of foam

separated by a 3.8-cm (1.5-inch) gap. The second layer was solid foam and the top layer was constructed of 6.4-cm (2.5-inch) strips separated again by a 3.8-cm (1.5-inch) gap, in which the explosives were placed.

The type explosive used was pentaerthritoltetranitrate (PETN) made into 85.0-grams/m (400-grains/ft) detonating cord (Primacord). The charge cavity shown in Figure 2 had a charge density of 14.6 kg/m^3 (0.91 lb/ft^3), with two strands of detonating cord in each gap adjacent to the top strips of foam, which ran transverse across the charge cavity. Variations in charge density were obtained by changing the number of strands of detonating cords and/or the size of the detonating cords. Just off the edge of the charge cavity, the 85.0-grams/m (400-grains/ft) detonating cord was spliced to 21.3-grams/m (100-grains/ft) detonating cord and then pigtailed into one bundle and connected to a blasting cap. This ensured that detonation was initiated simultaneously along one edge of the charge cavity.

The entire charge cavity was covered, after the explosives and detonating cord were placed, with a layer of 1.3-cm (0.5-inch) plywood on which 81 cm (32 inches) of uncompacted native soil overburden was placed. The charge cavity was designed to overlap the structure by 2.1 metres (7 feet) on each side to ensure a planar wave propagating from the surface and to minimize any edge effects in the test bed. Figure 2b shows the charge cavity during construction prior to placement of the overburden.

A total of nine Foam HEST tests were conducted. Seven tests, referred to as Foam HEST 1-7, were conducted over shallow-buried box-type structures as shown in Figure 1, and two tests, referred to as Element Tests 4 and 5, were conducted over smaller earth-covered slab elements. Results of Foam HEST 1-7, along with all data collected, are given in References 1-5, and results of Element Tests 1-5 (the first 3 tests were static) are given in Reference 7. In every test the charge cavity depth was 11.4 cm (4.5 inches) and the soil overburden depth was 0.8 m (32 inches). Charge densities and test bed areas for each test are listed in Table 1.

The airblast pressure gages used to measure the airblast overpressure-time history were positioned at ground level directly beneath the charge cavity. In every case, the gage used was a Kulite Model HKS-375. Details of the gage mount used in most of the tests are shown in Figure 3. The baffle shown in Figure 3 serves to protect the gage from very high frequency pressure spikes in the charge cavity. Details on the development of this particular gage mount are

given in Reference 8. Other gage mounting methods used are discussed in References 1 and 7.

Table 1

TEST BED PARAMETERS

Test	Charge Density		Test Bed Area	
	kg/m^3	(lb/ft^3)	m × m	(ft × ft)
Foam HEST 1	14.6	(0.91)	9.8 × 5.8	(32 × 19)
Foam HEST 2	43.9	(2.74)	9.8 × 5.8	(32 × 19)
Foam HEST 3	14.6	(0.91)	9.8 × 5.8	(32 × 19)
Foam HEST 4	14.6	(0.91)	9.8 × 6.1	(32 × 20)
Foam HEST 5	58.6	(3.6)	9.8 × 6.5	(32 × 21)
Foam HEST 6	29.2	(1.8)	9.8 × 6.1	(32 × 20)
Foam HEST 7	14.6	(0.91)	9.8 × 8.8	(32 × 29)
Element Test 4	21.9	(1.37)	1.8 × 1.8	(6 × 6)
Element Test 5	6.9	(0.43)	1.8 × 1.8	(6 × 6)

ANALYSIS

All airblast data collected in the nine Foam HEST tests are shown in Figures 4-29. Simulated surface burst weapons along with impulse records for the simulated weapon and the data records are also given in Figures 4-29. The pressure oscillations occurring during the first 2 msec are characteristic of the 11.4-cm (4.5-inch) charge cavity depth and are produced by reflection inside the expanding cavity. After about 2 msec the reflections stop because the cavity has expanded too much. These oscillations damp out very quickly in the soil cover.

Estimates of the surface burst nuclear yield and overpressure which most closely correspond to the airblast data record were found using the principle of least squares. These estimates are shown, along with the data, in Figures 4-29. The algorithm used to determine the simulated yield is described in Reference 9. In every case, the simulation is based on 10 msec of data. Also, the simulation is based on the best fit to the measured airblast pressure data. The impulse records are shown in Figures 4-29 as a measure of goodness of fit only, and were not used to determine the simulation because any electronic error occurring in the airblast pressure data would be cumulative in the integrated impulse record. Note that the simulation is sensitive to how much of the data record is used. The natural frequency of the structural models being tested was approximately

7 msec; therefore, the weapon overpressure simulated during approximately the first 10 msec was considered most important in these tests and only 10 msec of data were used. Simulated weapons and overpressures from each test are tabulated in Table 2.

Table 2

TEST RESULTS

Test	Charge Density		Gage Number	Weapon Yield		Peak Pressure	
	kg/m^3	(lb/ft^3)		TJ	(kt)	MPa	(psi)
Foam HEST 1	14.6	(0.91)	BP-3	1.05	(0.25)	13.0	(1,890)
			BP-5	0.80	(0.19)	12.0	(1,735)
Foam HEST 2	43.9	(2.74)	No Airblast Data Were Recovered				
Foam HEST 3	14.6	(0.91)	BP-1	3.2	(0.76)	11.5	(1,672)
			BP-2	3.1	(0.74)	13.7	(1,993)
			BP-4	0.92	(0.22)	13.7	(1,988)
			BP-7	0.55	(0.13)	18.4	(2,664)
			BP-8	4.6	(1.10)	12.6	(1,831)
			BP-9	0.36	(0.086)	20.0	(2,906)
Foam HEST 4	14.6	(0.91)	BP-1	2.9	(0.7)	13.2	(1,910)
			BP-3	4.2	(1.0)	13.0	(1,890)
Foam HEST 5	58.6	(3.6)	BP-3	32.6	(7.8)	54.1	(7,840)
			BP-4	2.8	(0.67)	117.6	(17,050)
			BP-5	11.7	(2.8)	72.8	(10,560)
			BP-6	15.1	(3.6)	71.4	(10,350)
Foam HEST 6	29.2	(1.8)	BP-2	8.79	(2.1)	49.8	(7,224)
			BP-3	7.95	(1.9)	45.6	(6,616)
			BP-5	2.8	(0.67)	63.9	(9,262)
			BP-6	2.8	(0.67)	63.9	(9,266)
Foam HEST 7	14.6	(0.91)	BP-1	9.96	(2.38)	16.2	(2,347)
			BP-2	9.75	(2.33)	14.6	(2,110)
			BP-5	2.50	(0.60)	20.2	(2,922)
			BP-6	1.17	(0.28)	22.0	(3,186)
			BP-7	3.66	(0.87)	12.7	(1,840)
			BP-8	3.95	(0.94)	12.3	(1,777)
Element Test 4	21.9	(1.37)	BP-1	0.11	(0.027)	22.7	(3,275)
Element Test 5	6.9	(0.43)	BP-3	0.042	(0.010)	6.0	(860)

The peak pressure in a HEST test is primarily dependent on charge density. A curve showing the charge density required to produce a given peak simulation overpressure is given in Reference 6 and is reproduced in Figure 30. Data shown in Figure 30 are average simulated overpressures from each test. There

is good agreement between data and predicted overpressure for 75 percent foam at charge densities less than about 24 kg/m^3 (1.5 lb/ft^3); however, at charge densities near 32 kg/m^3 (2 lb/ft^3) and greater the curve significantly underpredicts the simulated peak overpressure. The four tests conducted at 14.6 kg/m^3 (0.91 lb/ft^3) show good reproducibility with the average simulated peak pressure going from about 12.4 MPa (1800 psi) in Foam HEST 1 to about 15.8 MPa (2300 psi) in Foam HEST 7, and the overall average simulated peak overpressure is 14.9 MPa (2160 psi) using each of the 16 surviving airblast gages as an independent measurement.

Foam HEST 1 was designed by the Air Force Weapons Laboratory using the HEST DESIGN LOCKUP CODE developed at AFWL by Mr. Edward Seusy. This code is described in detail in Reference 6. All other tests in this paper repeated the Foam HEST 1 design using different charge densities. Surface burst weapon yield simulations shown in Figures 4-29 and tabulated in Table 2 varied from 0.042 TJ (0.010 kt) in Element Test 5 to approximately 32.6 TJ (7.8 kt) in Foam HEST 5. Simulated yields in the element tests were much less than expected because of edge effects in the relatively small test bed. In a small test bed, blowout around the edges will affect the simulation. Since foam HEST tests 1-7 were conducted on approximately 1/4-scale model structures, weapon yields should be multiplied by 64 to obtain the prototype simulation. Also, the element tests were conducted on approximately 1/8-scale model structures and thus yields should be multiplied by 512 to obtain the prototype simulation. Therefore, all weapons simulated could be classified as low to medium yield when scaled up to prototype size.

CONCLUSIONS

The Foam HEST described in this paper is an effective and economical method for simulating low yield nuclear overpressures in small-scale structural response experiments. Ground cover over the structural models may be important in damping out early time high pressure oscillation in the charge cavity. This is especially true if structural frequencies are close to the frequency of the oscillations. For small test beds, blowout around the edge can cause a significant reduction in the simulated yield.

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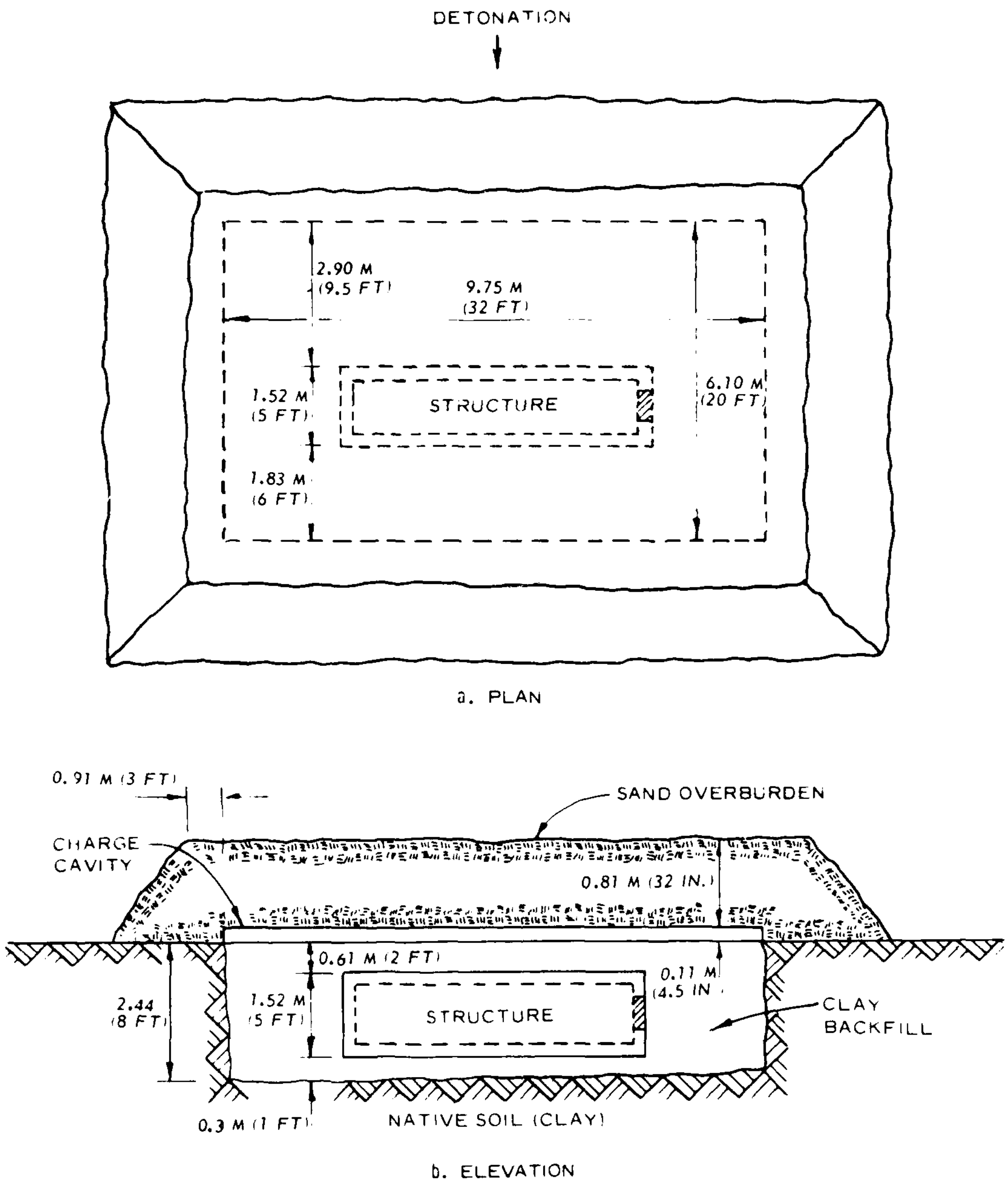
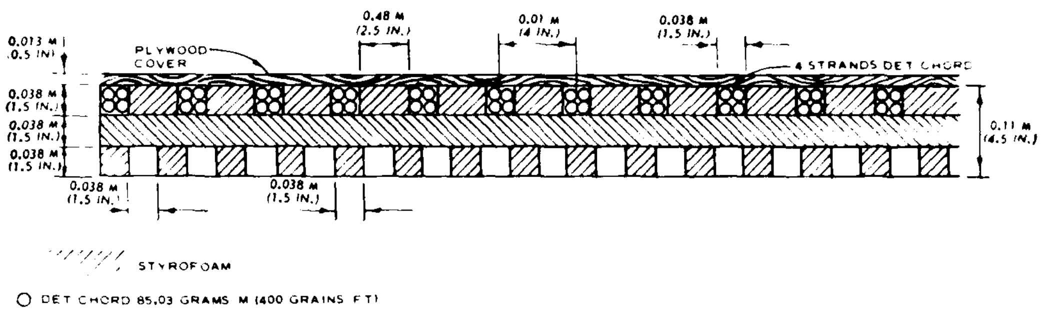
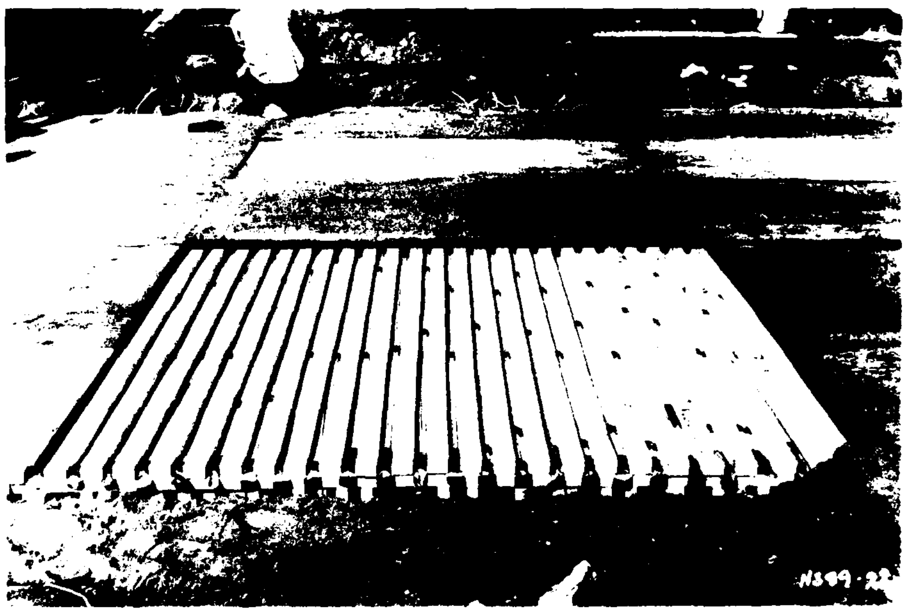


Figure 1 Typical Foam HEST configuration.

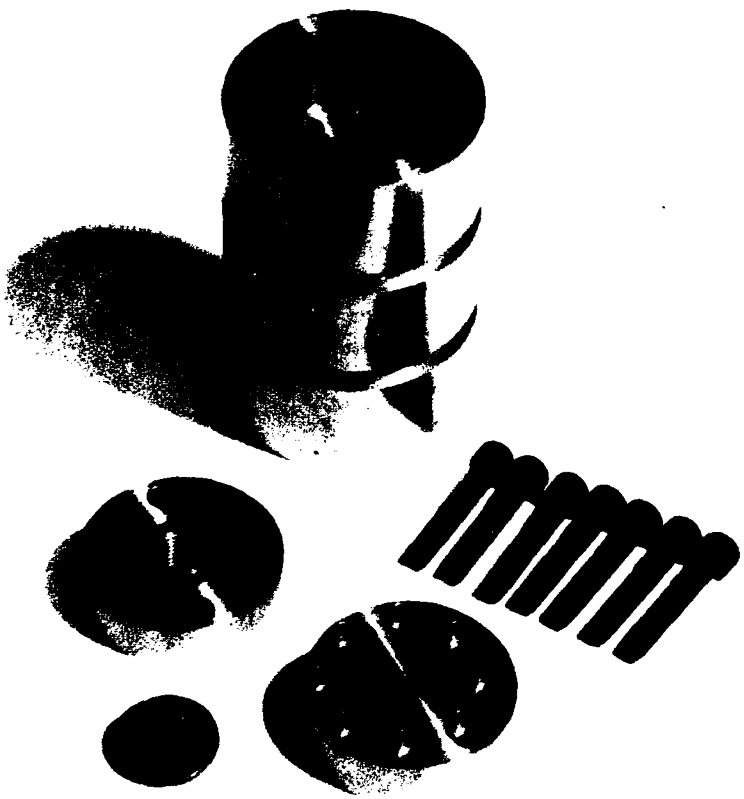


a. Typical charge cavity details.



b. Typical charge cavity under construction.

Figure 2 Typical charge cavity.



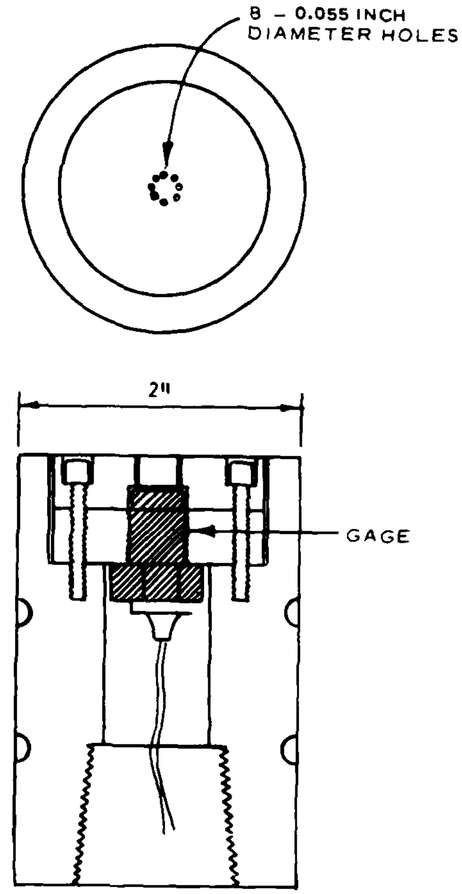


Figure 3 Airblast gage baffle mount.

FIG. 4. FOAM HEST 1, GAGE BP-3.

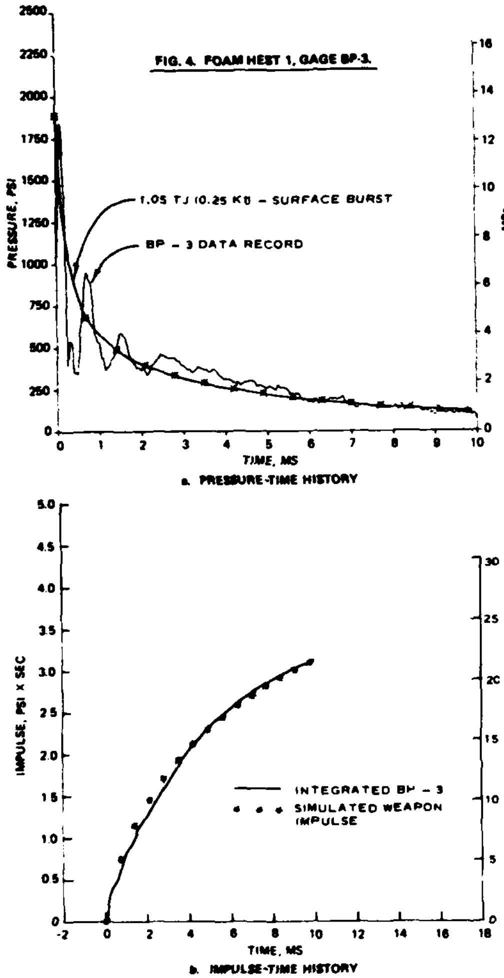


FIG. 5. FOAM HEST 1, GAGE BP-5.

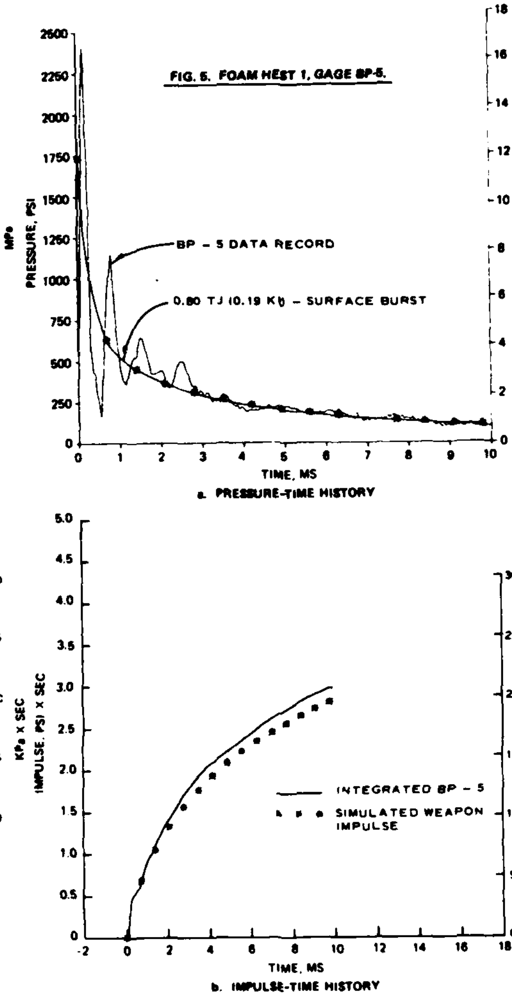
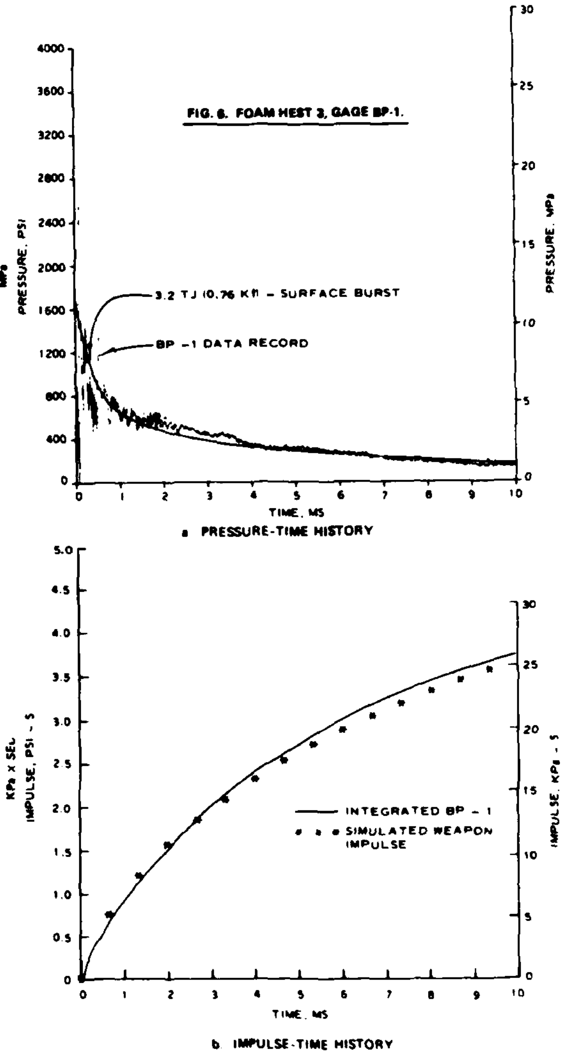


FIG. 6. FOAM HEST 3, GAGE BP-1.



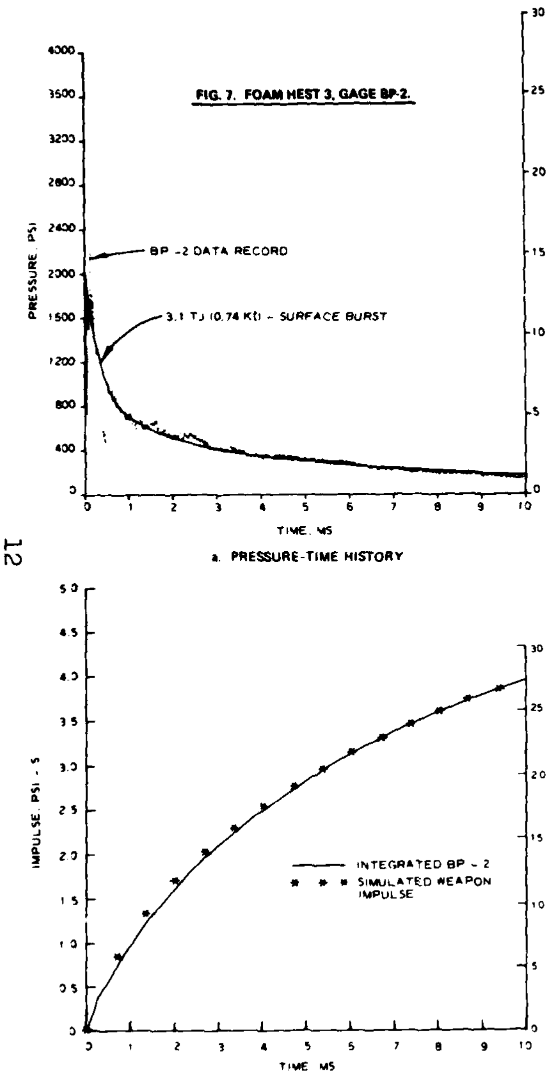


FIG. 7. FOAM HEST 3, GAGE BP-2.

a. PRESSURE-TIME HISTORY

b. IMPULSE-TIME HISTORY

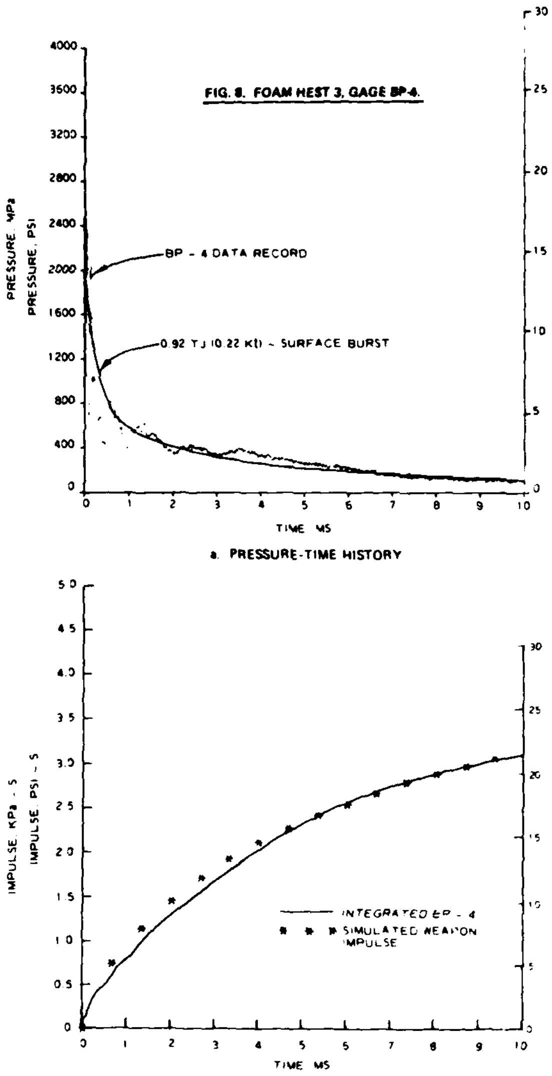


FIG. 8. FOAM HEST 3, GAGE BP-4.

a. PRESSURE-TIME HISTORY

b. IMPULSE-TIME HISTORY

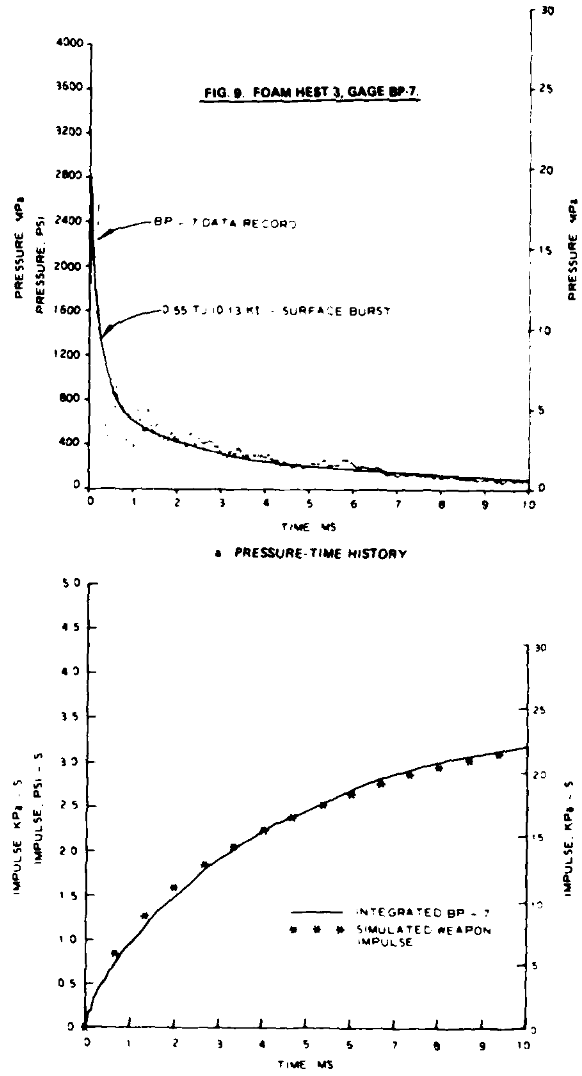


FIG. 9. FOAM HEST 3, GAGE BP-7.

a. PRESSURE-TIME HISTORY

b. IMPULSE-TIME HISTORY

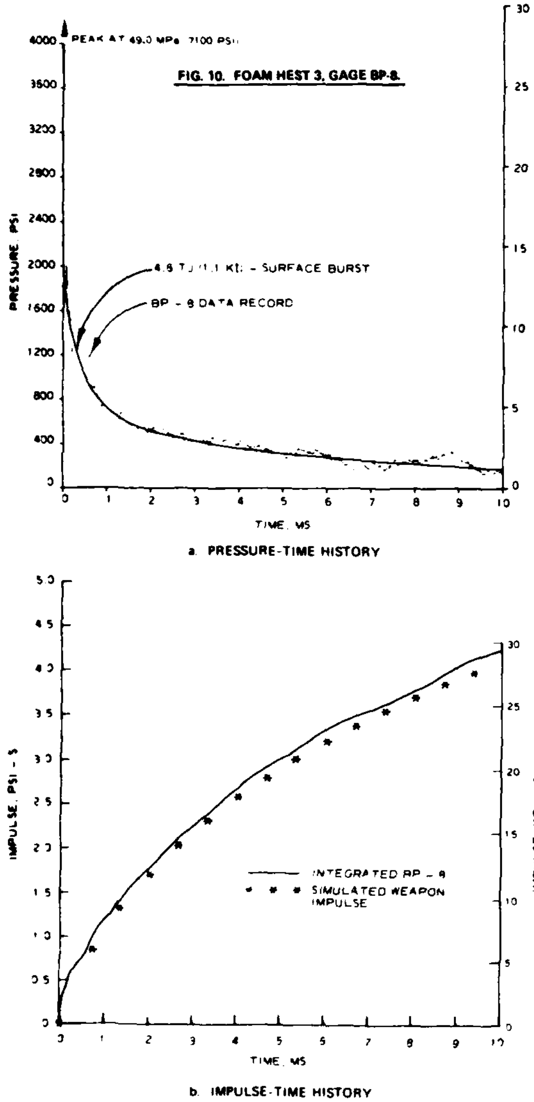


FIG. 10. FOAM HEST 3, GAGE BP-8.
PEAK AT 49.0 MPa (7100 PSI)
4.8 TJ (1.1 KT) – SURFACE BURST
BP – 8 DATA RECORD
PRESSURE, PSI
PRESSURE, MPa
TIME, MS
a. PRESSURE-TIME HISTORY
IMPULSE, PSI – S
IMPULSE, KPa – S
INTEGRATED BP – 8
SIMULATED WEAPON IMPULSE
TIME, MS
b. IMPULSE-TIME HISTORY

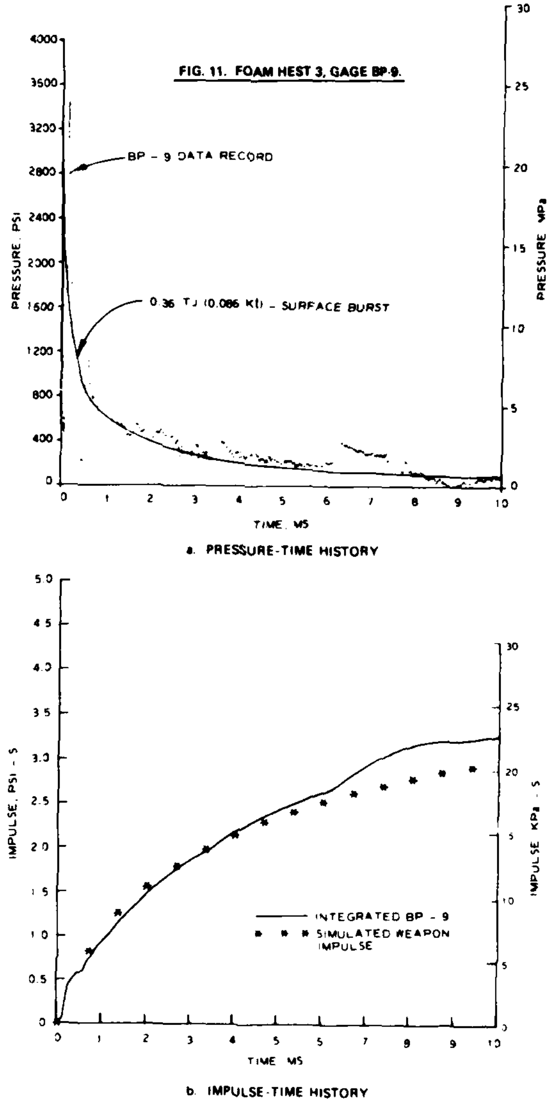


FIG. 11. FOAM HEST 3, GAGE BP-9.
BP – 9 DATA RECORD
0.36 TJ (0.086 KT) – SURFACE BURST
PRESSURE, PSI
PRESSURE, MPa
TIME, MS
a. PRESSURE-TIME HISTORY
IMPULSE, PSI – S
IMPULSE, KPa – S
INTEGRATED BP – 9
SIMULATED WEAPON IMPULSE
TIME, MS
b. IMPULSE-TIME HISTORY

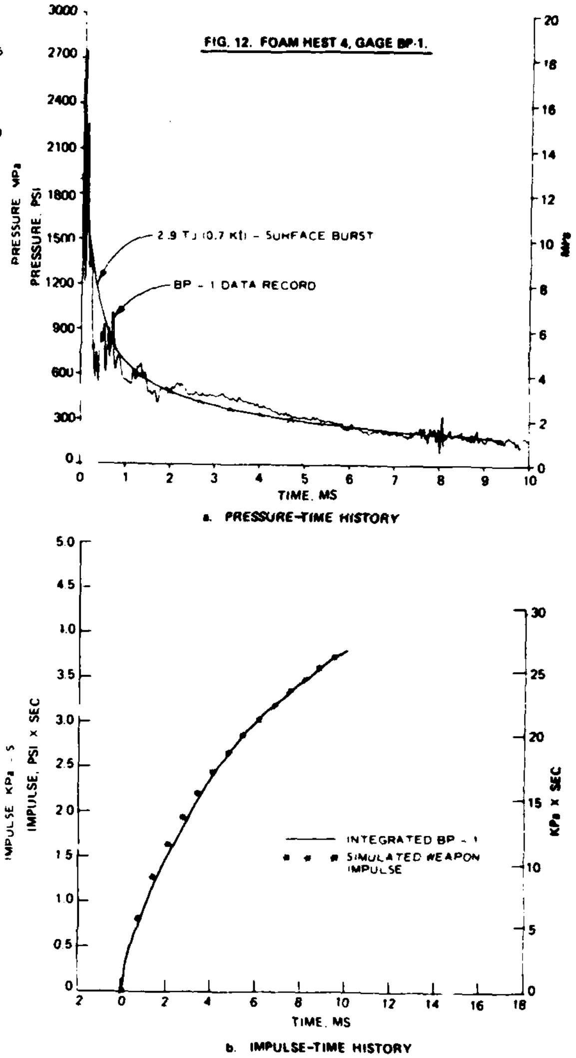
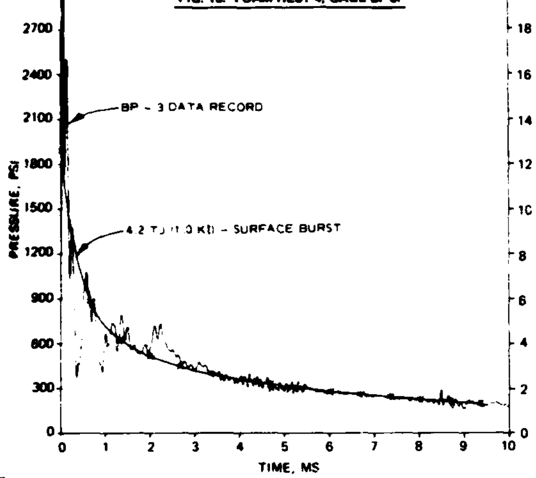
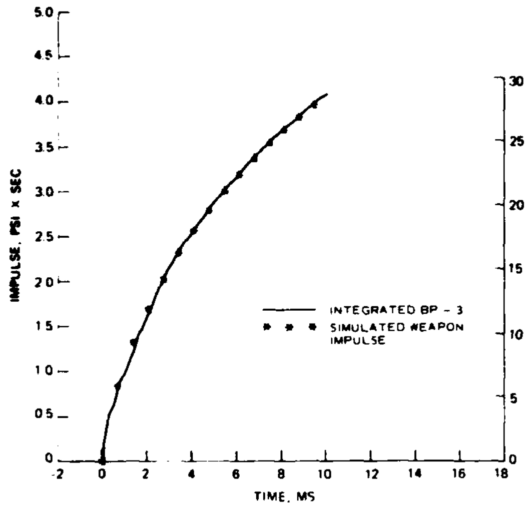


FIG. 12. FOAM HEST 4, GAGE BP-1.
2.9 TJ (0.7 KT) – SURFACE BURST
BP – 1 DATA RECORD
PRESSURE, PSI
MPa
TIME, MS
a. PRESSURE-TIME HISTORY
IMPULSE, PSI x SEC
KPa x SEC
INTEGRATED BP – 1
SIMULATED WEAPON IMPULSE
TIME, MS
b. IMPULSE-TIME HISTORY

FIG. 13. FOAM HEST 4, GAGE BP-3.

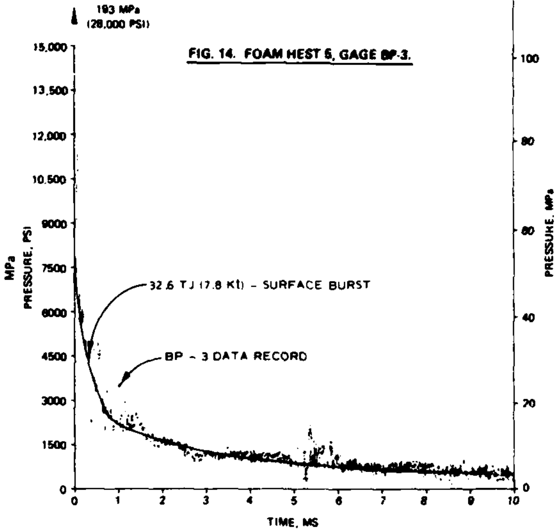


a. PRESSURE-TIME HISTORY

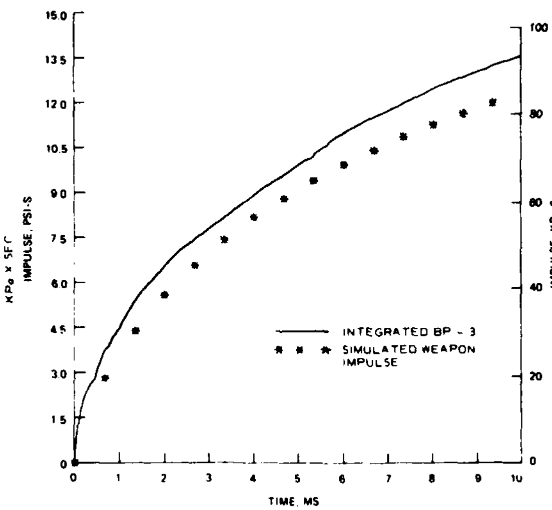


b. IMPULSE-TIME HISTORY

FIG. 14. FOAM HEST 5, GAGE BP-3.

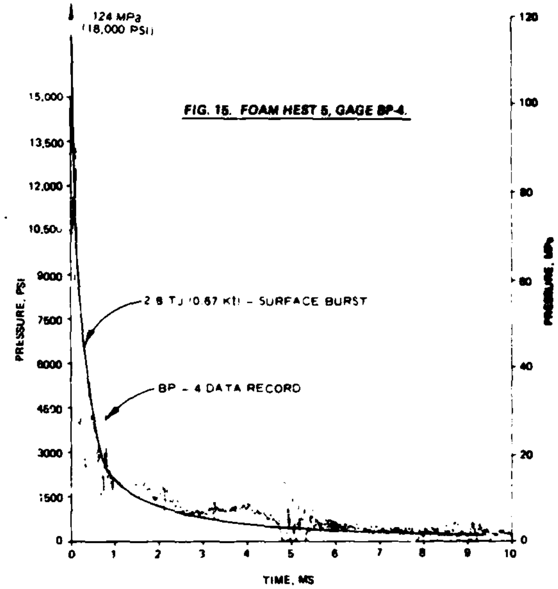


a. PRESSURE-TIME HISTORY

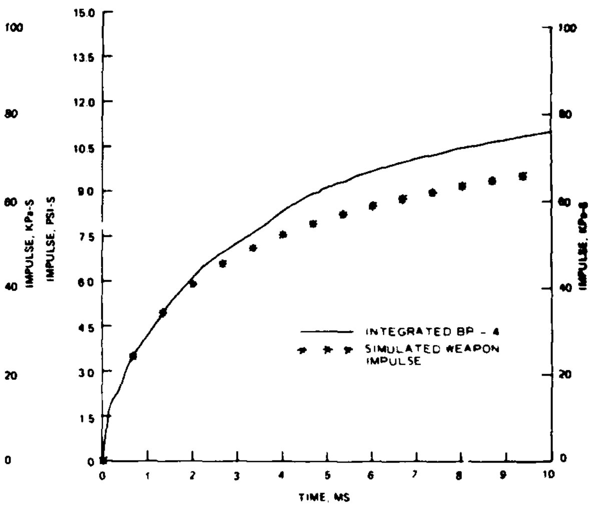


b. IMPULSE-TIME HISTORY

FIG. 15. FOAM HEST 5, GAGE BP-4.



a. PRESSURE-TIME HISTORY



b. IMPULSE-TIME HISTORY

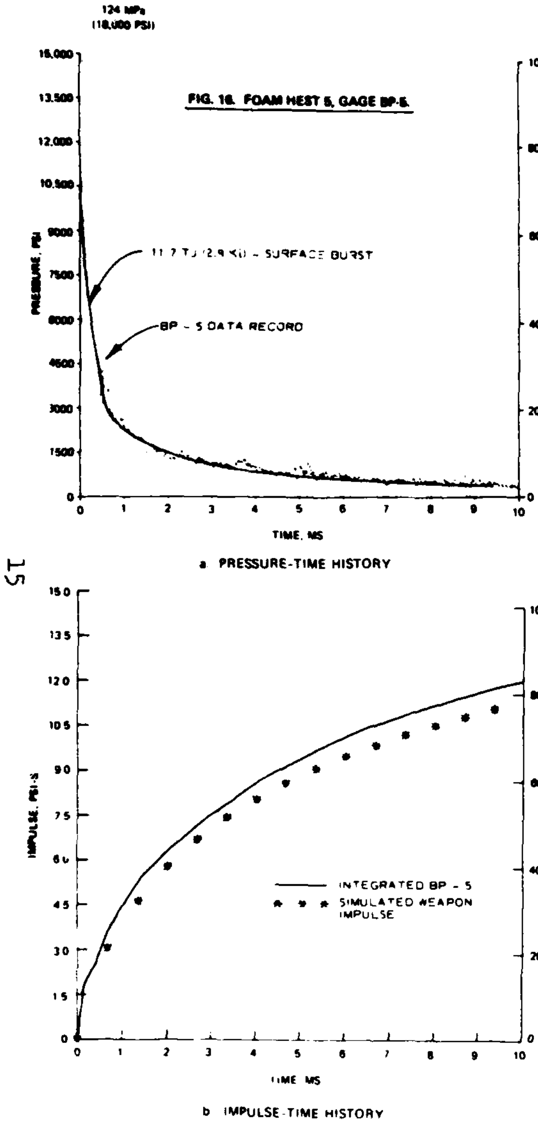


FIG. 16. FOAM HEST 5, GAGE BP-5.

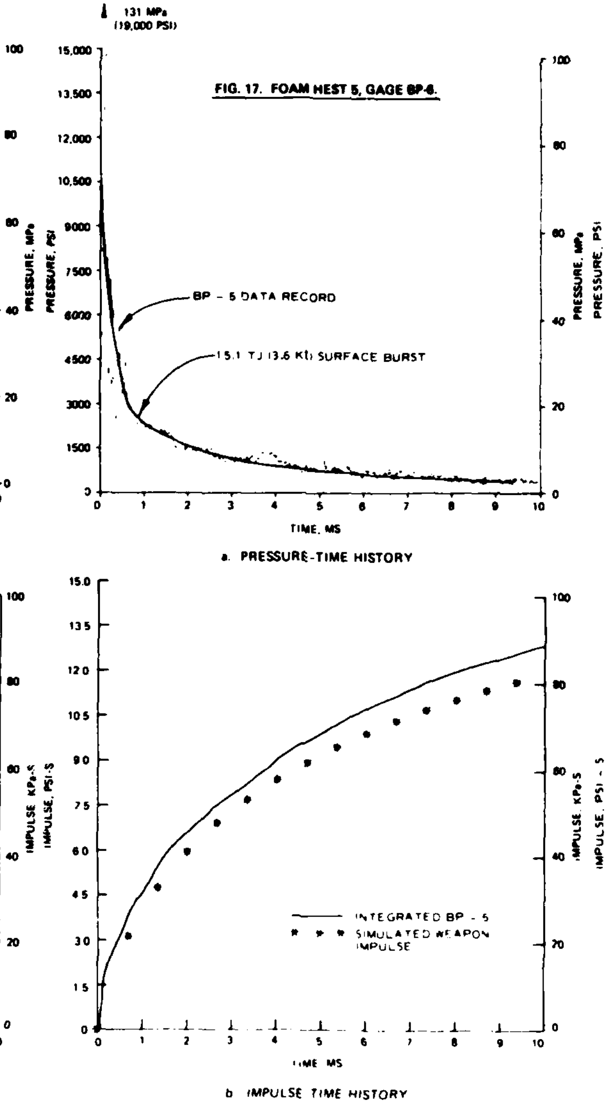


FIG. 17. FOAM HEST 5, GAGE BP-6.

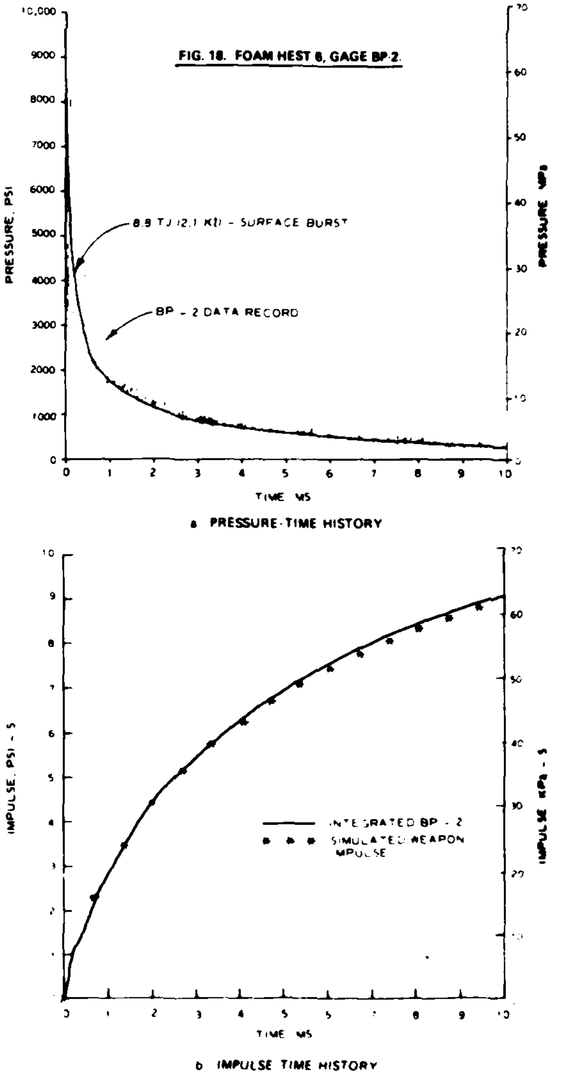
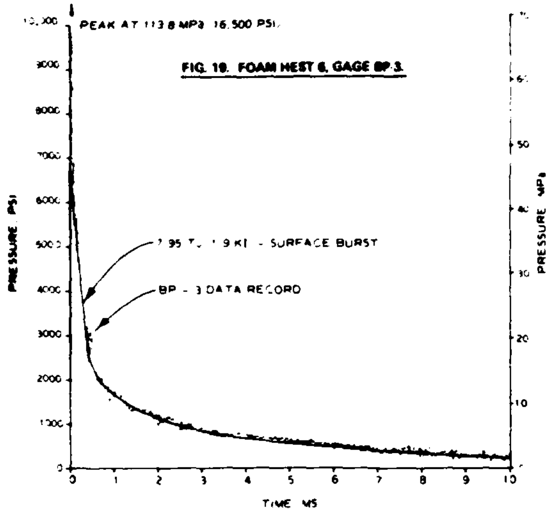
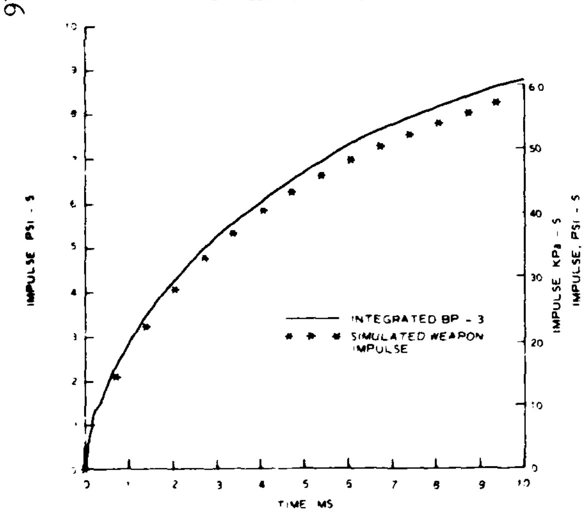


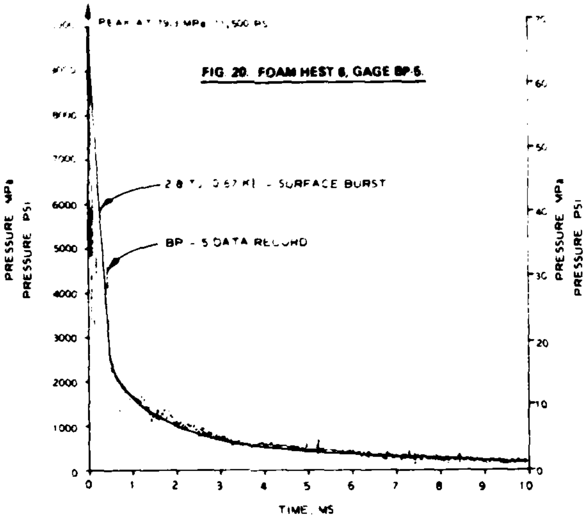
FIG. 18. FOAM HEST 6, GAGE BP-2.



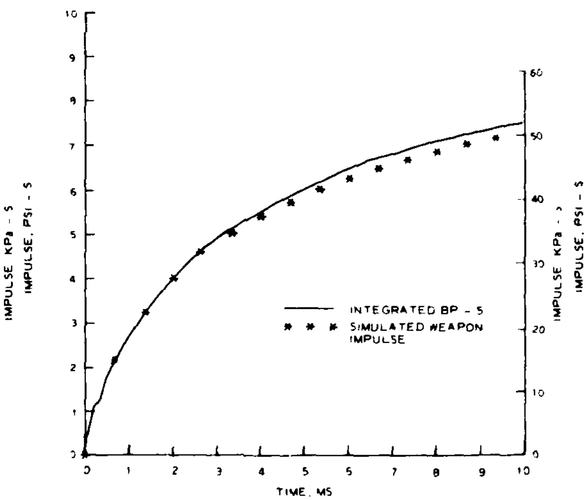
a. PRESSURE-TIME HISTORY



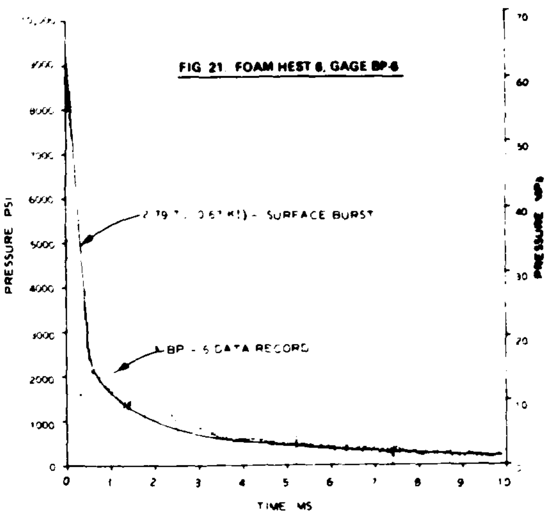
b. IMPULSE-TIME HISTORY



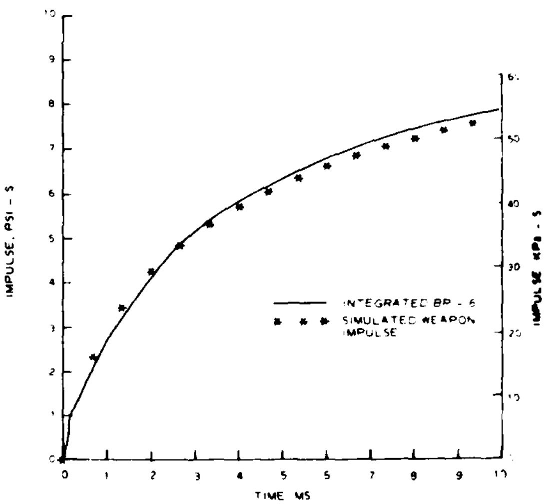
a. PRESSURE-TIME HISTORY



b. IMPULSE-TIME HISTORY



a. PRESSURE-TIME HISTORY



b. IMPULSE-TIME HISTORY

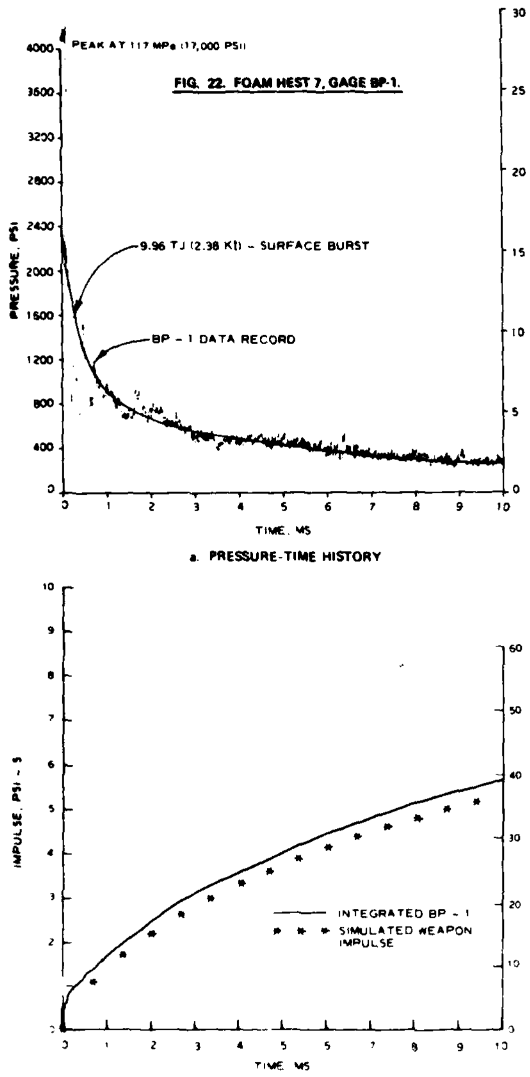


FIG. 22. FOAM HEST 7, GAGE BP-1.

a. PRESSURE-TIME HISTORY

b. IMPULSE-TIME HISTORY

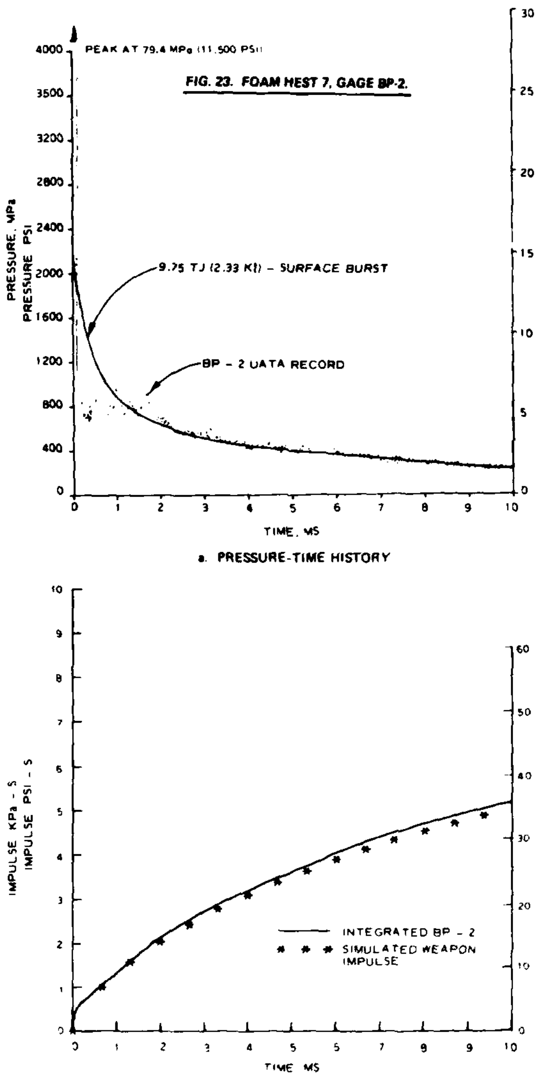


FIG. 23. FOAM HEST 7, GAGE BP-2.

a. PRESSURE-TIME HISTORY

b. IMPULSE-TIME HISTORY

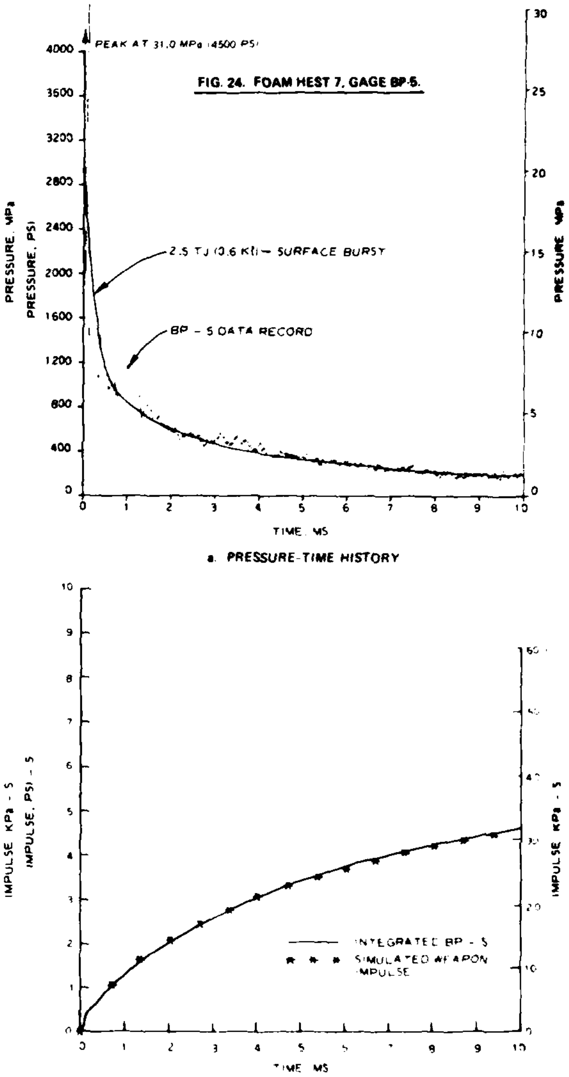
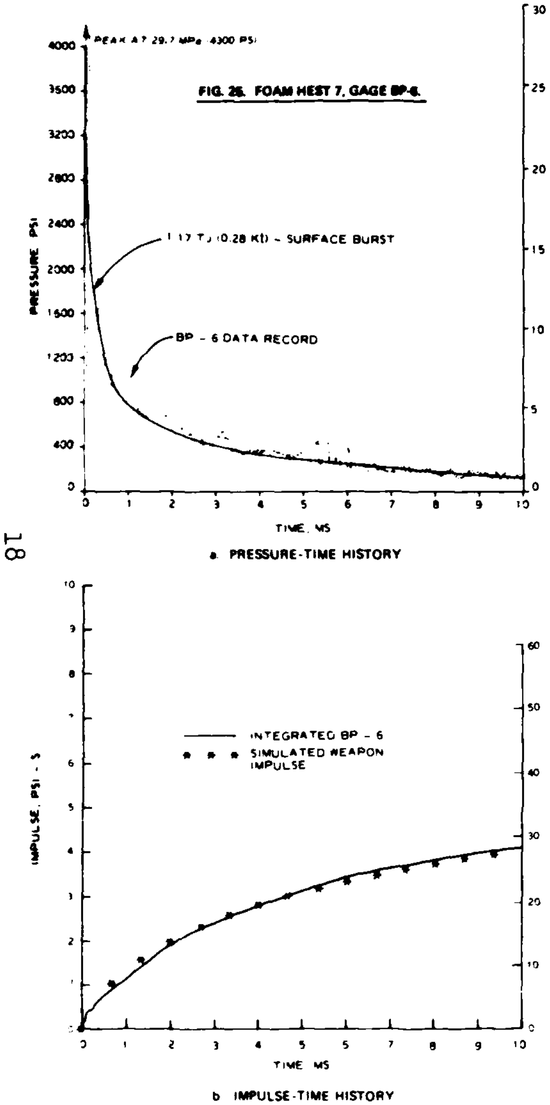
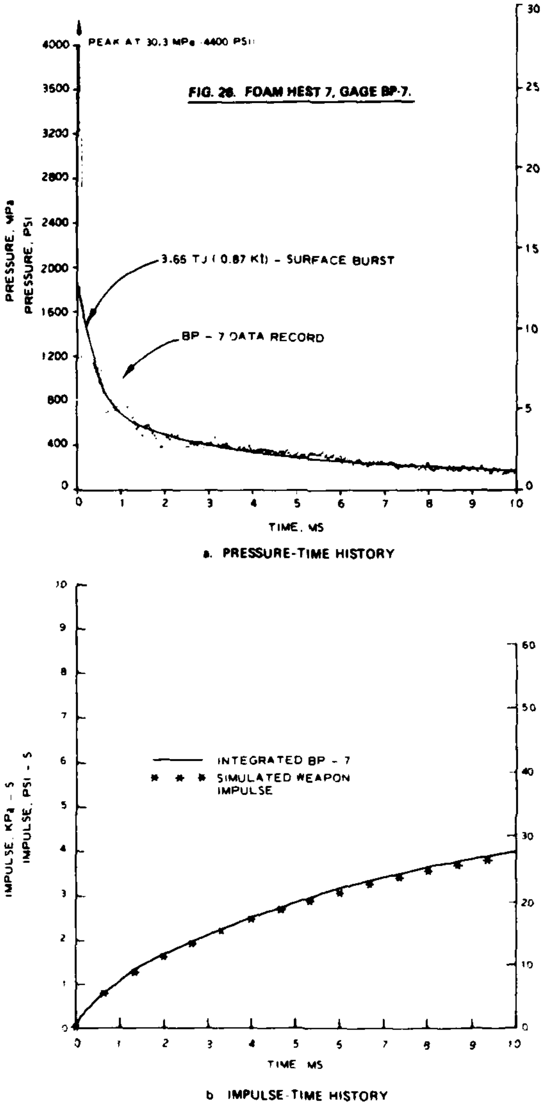


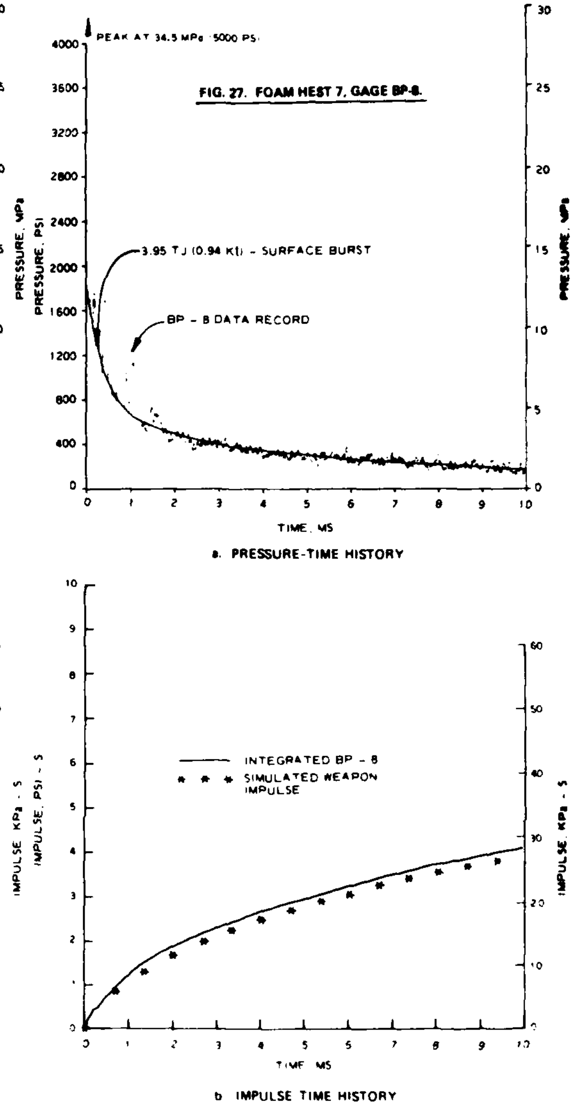
FIG. 24. FOAM HEST 7, GAGE BP-5.

a. PRESSURE-TIME HISTORY

b. IMPULSE-TIME HISTORY


PEAK AT 29.7 MPa (4300 PSI)
FIG. 25. FOAM HEST 7, GAGE BP-6.
1.17 TJ (0.28 KT) – SURFACE BURST
BP – 6 DATA RECORD
PRESSURE, PSI
PRESSURE, MPa
TIME, MS
a. PRESSURE-TIME HISTORY
INTEGRATED BP – 6
SIMULATED WEAPON IMPULSE
IMPULSE, PSI – S
IMPULSE, KPa – S
TIME MS
b. IMPULSE-TIME HISTORY


PEAK AT 30.3 MPa (4400 PSI)
FIG. 26. FOAM HEST 7, GAGE BP-7.
3.66 TJ (0.87 KT) – SURFACE BURST
BP – 7 DATA RECORD
PRESSURE, PSI
PRESSURE, MPa
TIME, MS
a. PRESSURE-TIME HISTORY
INTEGRATED BP – 7
SIMULATED WEAPON IMPULSE
IMPULSE, PSI – S
IMPULSE, KPa – S
TIME MS
b. IMPULSE-TIME HISTORY


PEAK AT 34.5 MPa (5000 PSI)
FIG. 27. FOAM HEST 7, GAGE BP-8.
3.95 TJ (0.94 KT) – SURFACE BURST
BP – 8 DATA RECORD
PRESSURE, PSI
PRESSURE, MPa
TIME, MS
a. PRESSURE-TIME HISTORY
INTEGRATED BP – 8
SIMULATED WEAPON IMPULSE
IMPULSE, PSI – S
IMPULSE, KPa – S
TIME MS
b. IMPULSE TIME HISTORY

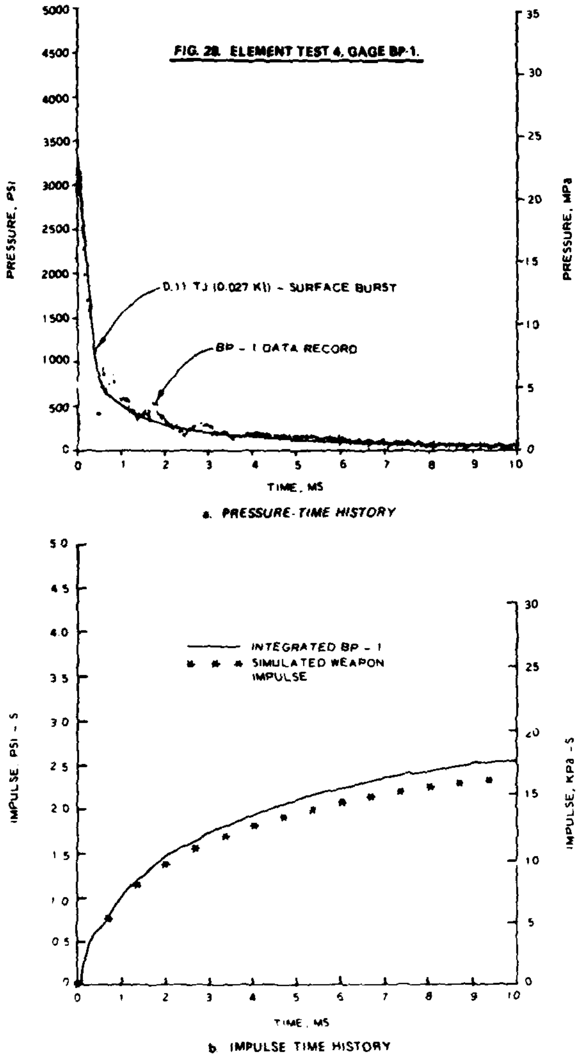


FIG. 28. ELEMENT TEST 4, GAGE BP-1.

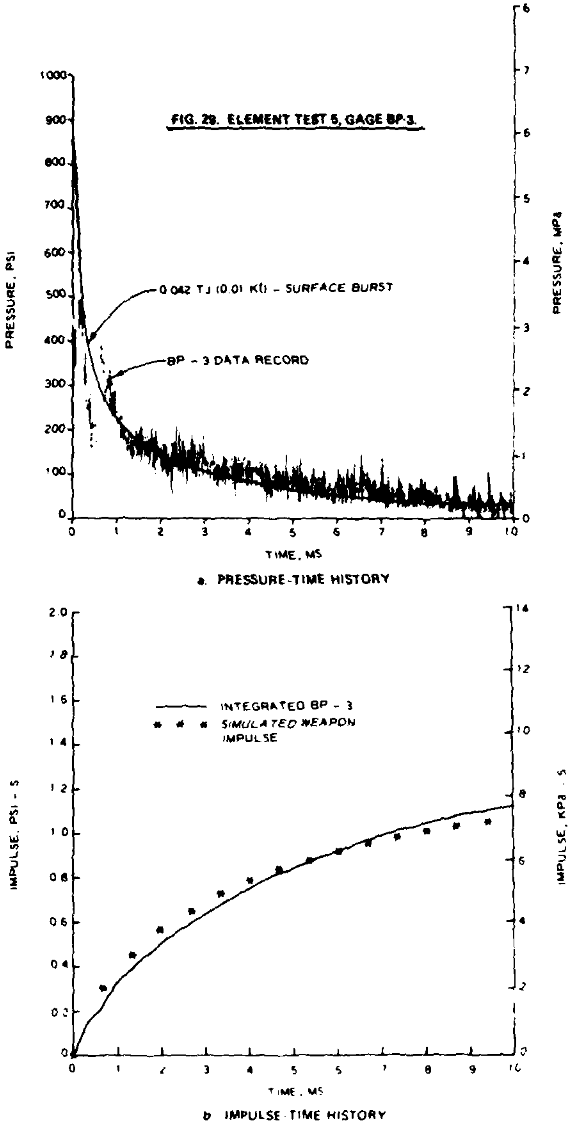


FIG. 29. ELEMENT TEST 5, GAGE BP-3.

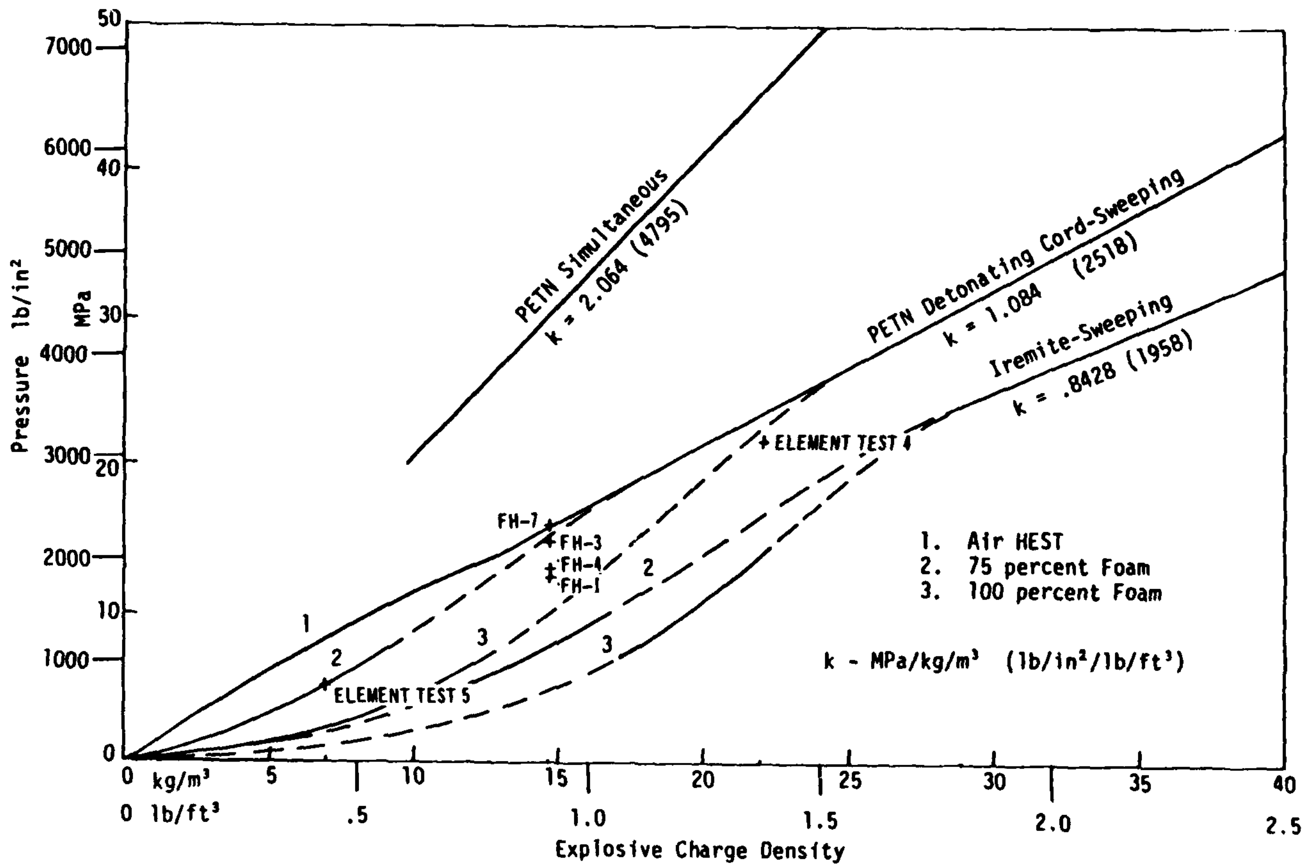


Figure 30 Peak simulation pressure versus charge density (from Ref. 6).

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Kiger, S. A.
  Use of a Foam HEST to simulate low-yield nuclear overpressures : final report / by S. A. Kiger (Structures Laboratory, U.S. Army Engineer Waterways Experiment Station). -- Vicksburg, Miss. : The Station ; Springfield, Va. : available from NTIS, [1981].
  20 p. : ill. ; 27 cm. -- (Miscellaneous paper / U.S. Army Engineer Waterways Experiment Station ; SL-81-12)
  Cover title.
  "July 1981."
  "Prepared for Defense Nuclear Agency and Office, Chief of Engineers, U.S. Army under DNA Subtask Y99QAXSC062, Work Unit 42, and OCE R&D Project 4A762719AT40, Task A0, Work Unit 008."
  Bibliography: p. 7.

  1. Blast effect. 2. Computer simulation. 3. Explosives. 4. Nuclear explosions. 5. Shock waves.

Kiger, S. A.
  Use of a Foam HEST to simulate low-yield nuclear : ... 1981.
(Card 2)

I. United States. Defense Nuclear Agency. II. United States. Army. Corps of Engineers. Office of the Chief of Engineers. III. U.S. Army Engineer Waterways Experiment Station. Structures Laboratory. IV. Title V. Series: Miscellaneous paper (U.S. Army Engineer Waterways Experiment Station) ; SL-81-12.
TA7.W34m no.SL-81-12

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